

On the basis of organic matter content, soils are characterized as mineral or organic. Mineral soils form most of our cultivated land and may contain from a mere trace to 20 to 30% organic matter ([Table 5.1](#)). On the contrary, organic soils contain 80% or more organic matter. Marshes, bogs, and swamps provide conditions suitable for the accumulation of large amounts of organic matter. Organic soils or histosols are found in cold glacial regions such as parts of Minnesota, Wisconsin, and Michigan in the United States, large areas in Russia and Canada, and in several countries of Europe, namely, Germany, Holland, Norway, Sweden, Poland, and the United Kingdom. Histosols also occur in warmer regions of the world such as Kari soils in Kerala, India. The discussion on soil organic matter in this chapter deals mainly with the organic matter of mineral soils.

Most of the soil organic matter originates from plant tissue; animal tissue is also derived from plant products. Plant residues contain 60 to 90% moisture, and the rest is dry matter. On a weight basis, the dry matter is mostly carbon and oxygen (about 40% each), with less than 10% each of hydrogen and inorganic elements (ash). Therefore C, H, and O dominate the organic matter in soil. Other elements such as S, N, P, K, Ca, Mg, and micronutrients, although present in small amounts, are important from the viewpoint of soil fertility management. Soil organic matter is the primary source of native nutrients from a soil.

When plant residues are added to a soil, various organic compounds undergo decomposition. Sugars, starches, and proteins decompose rapidly, while cellulose, fats, waxes, and lignins decompose slowly; lignin decomposes very slowly. There are five major kinds of products from the decomposition of plant or animal residues.

1. CO_2 —Evolution of CO_2 can be easily observed. The rate of decomposition of various plant and animal residues is determined by measuring the rate of evolution of CO_2 .

Table 5.1 Carbon and Nitrogen Contents of Soils under Various Moisture-Temperature Interactions^a

Temperature–moisture interaction zone	Carbon (Mg ha ⁻¹ m ⁻¹)	Nitrogen (Mg ha ⁻¹ m ⁻¹)	Carbon/nitrogen
Boreal dry bush	102	6.3	16
Boreal wet forest	150	9.8	15
Boreal rain forest	320	15.0	22
Cool temperature desert bush	99	7.8	13
Cool temperature grassland	133	10.3	13
Cool temperature wet forest	120	6.3	19
Cool temperature rain forest	200	8.0	25
Warm temperature desert bush	60	3.0	20
Warm temperature moist forest	93	6.5	14
Warm temperature wet forest	270	18.0	14
Warm temperature rain forest	270	7.0	38
Tropical desert bush	10	0.5	20
Tropical dry forest	100	8.9	11
Tropical wet forest	145	6.6	22
Tropical rain forest	180	6.0	30

^aAdapted from Zinke et al. (1984) and Paul and Clark (1989).

2. Heat or energy—This can be easily measured. Energy released is utilized by the soil microorganisms. Plant tissue has a heat value approximating 4 to 5 K calories per gram of air-dry substance.
3. Water—This is released as a product of several enzymatic oxidations of organic carbon compounds.
4. Plant nutrients—N, S, P, Ca, Mg, K, etc., are released, which is the primary goal of applying farmyard manure or other organic residues to a field. Some of the released nutrients may again be immobilized or fixed by accompanying microbiological/chemical reactions. The much talked about “organic farming” aims at meeting all or most plant nutrient needs by the use of farm residues and biological nitrogen fixation.
5. Soil humus—This is a combination of the residues of the added organic matter, as well as resynthesized microbial tissue that is resistant to microbial action. Humus is an important component of soil and plays a major role in determining the physical and physico-chemical properties of a soil.

5.1. HUMUS, ITS STRUCTURE AND PROPERTIES

Humus is a complex mixture of dark-brown, amorphous and colloidal substances modified from the original plant tissue or synthesized by the various soil organisms and is resistant to microbial decomposition. The contribution

Table 5.2 Contribution of Microbial Biomass to Soil Organic Matter in 0–10 cm Soil Layer^a

Region	Treatment	Microbial biomass	
		mg kg ⁻²	% Soil organic
U.S.	Wheat-fallow	266	2.2
	Annual crop ^b	421	2.8
	Grass pastures	1158	5.2

^aPlots established on Walla Walla soil at the Columbia Basin Agricultural Research Center, Pendelton, Oregon, in 1931; samples collected in 1987.

^bContinuous wheat and wheat-pea rotation.

From Collins et al., 1992. Soil Sci. Soc. Am. J. 56:783–788. With permission of the Soil Science Society of America, Madison, WI.

of microbial biomass to soil organic matter can vary from 2 to 5% (Table 5.2). Microbial biomass is greatest in soils receiving manure or green manuring. Also grass pastures have much more microbial biomass, which contributes to increased soil organic C.

The general scheme of analyzing humus involves extraction with an alkaline solution followed by reaction with an acid. The portion of humus that cannot be extracted by an alkaline solution is known as humin. The portion of the alkaline extract that precipitates on acidification is known as humic acid, while that which remains in acid solution is known as fulvic acid (Figure 5.1). The molecular weight ranges from several hundred for fulvic acids to over 300,000 for humic acids and humin (Stevenson, 1982).

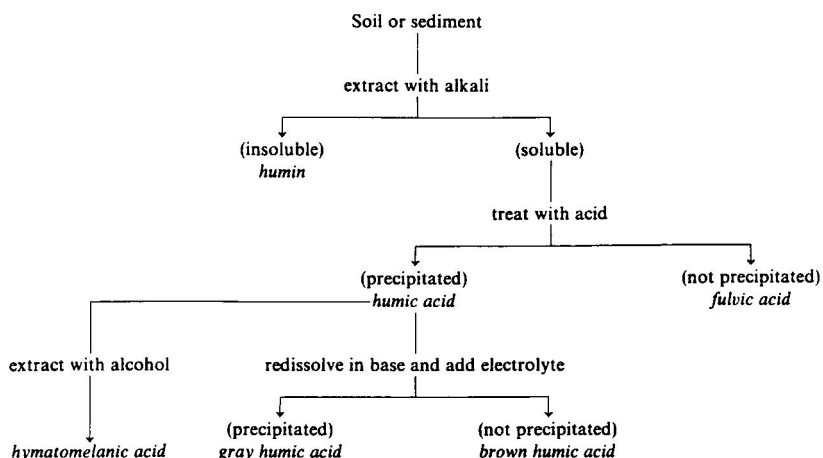


Figure 5.1. Scheme for separation of soil humus. (From Stevenson, 1982. *Humus Chemistry: Genesis, Composition, Reactions*, p. 43. With permission of John Wiley & Sons.)

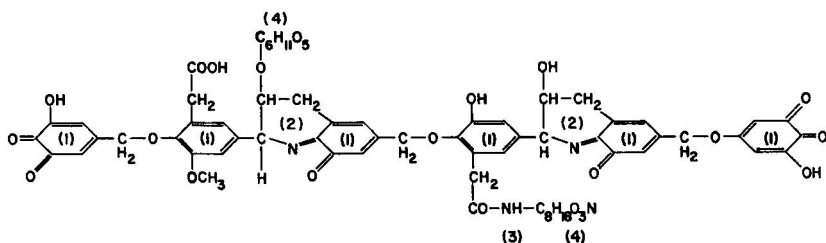


Figure 5.2. The structure of humic acid molecules after Dragunov. (From Kononova et al., 1961. *Soil Organic Matter — Its Nature Its Role in Soil Formation and in Soil Fertility*, p. 65.

Very complicated structural formulas for the humic acid molecule have been proposed; one formula, given by Dragunov in 1948 (Kononova et al., 1961), is shown in Fig. 5.2. Orlov (1985) has suggested a probable scheme of a structural cell of humic acid from a chernozem (Figure 5.3). As is evident from Figures 5.2 and 5.3, the chemical formulas for different fractions of soil humus are difficult to write due to the extremely complex nature of compounds.

Humus has properties distinctly different from the original plant tissue and has its own identity as a natural body, though exceedingly variable and heterogenous. Some of the properties exhibited by soil humus, which are well known and important from the viewpoint of soil fertility management, include the following:

1. Humus particles become bonded to clay or other silicate surfaces, leading to the formation of clay-humus complexes.
2. Humus stores and releases soil N.
3. Humus possesses buffering capacity
4. Humus possesses cation exchange capacity
5. Humus possesses anion exchange capacity
6. Humus adsorbs pesticides and other agricultural chemicals.

The core material in soil humus is lignin, which is made up of basic units of a 6-carbon benzene ring with a 3-carbon side chain attached to it, giving a basic formula (C₆-C₃)_n, where n is the number of monomers linked together to form the highly polymerized molecule. The breakdown of the lignin molecule leads to the release of C₆-C₃ units (Stevenson, 1982). A common C₆-C₃ monomer in lignin is coniferyl alcohol, which can be transformed to phenols (i.e., phenolic acids) and quinones as shown in Figure 5.4.

Soil humus is therefore characterized by having benzene type monomers. Stevenson and Olsen (1989) have proposed a dimer structural unit as a building block for soil humus. This dimer unit is shown in Figure 5.5 and is made up of two benzene based monomers, one of them having an amino group (-NH₂).



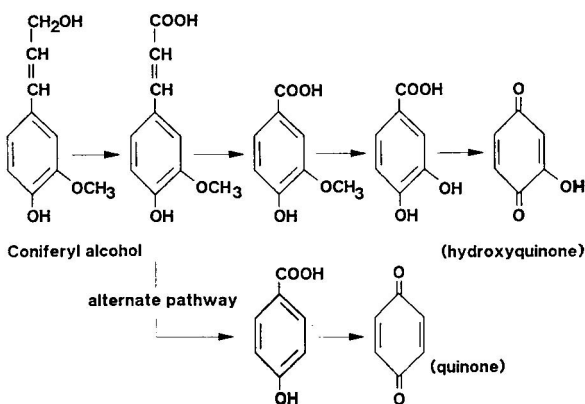


Figure 5.4. Biochemical conversion of coniferyl alcohol, a lignin binding unit to phenols and quinones. (From Stevenson and Olsen, 1989. *J. Agron. Educ.* 18:84–88. With permission of the American Society of Agronomy, Madison, WI.)

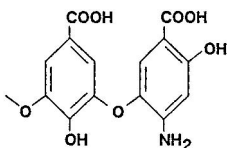


Figure 5.5. A dimer structural unit as the building block of soil humus. (From Stevenson and Olsen, 1989. *J. Agron. Educ.* 18:84–88. With permission of the American Society of Agronomy, Madison, WI.)

The dimer in Figure 5.5 has a molecular weight of approximately 250 and includes the more important functional groups found in humic substances. The C:N ratio of the dimer is 14:1, which is of the order of that found for soil humus. The chemical composition, C:N ratio, and some other properties of humic acids and fulvic acids are given in [Table 5.3](#).

Because the types of monomers could be numerous, and the ways in which they combine is great, structures of the resulting macromolecules are exceedingly variable and complex.

The dimer structure would explain why nitrogen is released on decomposition of soil humus. It also conveniently explains why the cation exchange capacity (CEC) of soil organic matter increases with an increase in soil pH ([Figure 5.6](#)). In addition to the exchange of cations, the closely associated COOH and OH groups also permit chelation of heavy metal ions. Similarly, organic molecules of herbicides and other pesticides become attached to OH or COOH radicals, explaining why soil organic matter or humus can adsorb

Table 5.3 Chemical Composition of Humic Acids (HA) and Fulvic Acids (FA) From Some Soils

Soil	HA or FA	C	H	O	N	C:N	Total acidity	Carboxyl (-COOH)	Phenolic/enolic (-OH)
		(%)						(mmol g ⁻¹)	
Alfisol	HA	56.8	5.3	33.3	4.6	12.3	6.8	3.9	2.8
Inceptisol	HA	51.4	5.8	38.7	6.0	8.6	6.0	2.4	3.6
Spodosol	HA	49.0	4.6	45.7	0.7	70.0	12.0	9.2	2.8
Spodosol	FA	50.9	3.3	44.7	0.7	72.7	12.4	9.1	3.3
Ultisol	HA	48.7	4.8	42.7	3.8	12.8	8.7	2.7	6.0
Ultisol	FA	40.6	4.1	53.9	1.4	29.0	10.2	8.8	1.4
Histosol	HA	57.0	4.5	34.8	3.3	17.3	7.2	3.1	4.2
Histosol	FA	54.5	5.3	37.6	1.9	28.7	8.6	4.0	4.6

Adapted from Hayes (1991).

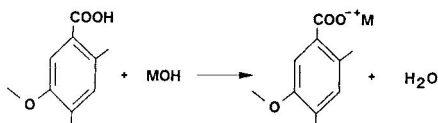


Figure 5.6. Effect of pH on CEC of dimer. (From Stevenson and Olsen, 1989. *J. Agron. Educ.* 18:84–88. With permission of the American Society of Agronomy, Madison, WI.)

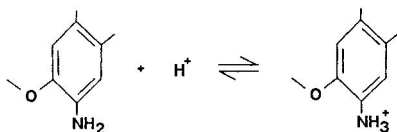


Figure 5.7. Anion exchange properties of dimer under acid conditions. (From Stevenson and Olsen, 1989. *J. Agron. Educ.* 18:84–88. With permission of the American Society of Agronomy, Madison, WI.)

pesticides, and necessitate the application of higher doses on soils having higher organic matter content. The dimer structure also easily explains why the humus has anion exchange properties (Figure 5.7).

The tendency of humus to be bonded to clay and other silicate surfaces can easily be illustrated through linkages with polyvalent cations (M) and H-bonding (Figure 5.8).

Thus several properties of humus or soil organic matter can be explained using the dimer unit proposed by Stevenson (1982). However, it may be pointed out that this is an oversimplified view; the nature and properties of soil organic matter is complex and there is still much more to be learned.

5.2. C:N RATIO

C:N ratio of soil organic matter is an important property. Since C makes up a large and rather definite proportion of soil organic matter, it is not surprising that the C:N ratio of soils tends to be fairly constant, generally between 8:1 to 15:1, the median being between 10:1 to 12:1. Temperature and precipitation influence the C:N ratio in soil organic matter. When rainfall is constant, the C:N ratio is lower in warmer than in cooler regions. Similarly, when annual temperatures are about the same, the C:N ratio tends to be lower in drier regions.

Since the C:N ratio of a soil tends to be constant, the C:N ratio of added organic residues to soil assumes considerable importance. When a residue having a high C:N ratio such as wheat straw is added to soil, there is a sudden increase in the evolution of CO_2 due to increased microbial activity. Concomitant to this is the depression in soil nitrates (Figure 5.9). This is well

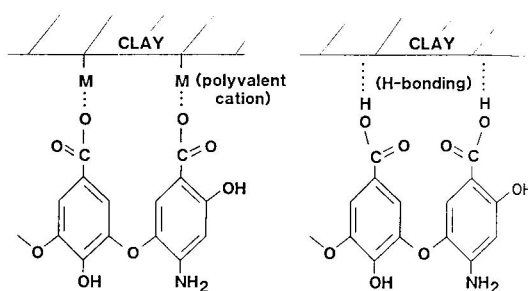


Figure 5.8. Binding of dimer unit to clay particles. (From Stevenson and Olsen, 1989. *J. Agron. Educ.* 18:84–88. With permission of the American Society of Agronomy, Madison, WI.)

demonstrated by yellow crop plants with stunted growth in those parts of the field where straw has accumulated, such as areas used for threshing the previous crop in developing countries, where combine harvesting is not yet practiced. After much of the C of the added residues has been oxidized, CO_2 evolution slows down and nitrification restarts. This does not happen when leguminous crop residues having narrow C:N ratios (20 to 30:1) are added to the soil. In such instances, nitrates tend to accumulate after a short period of immobilization because C availability limits microbial activity more than N availability.

5.3. FACTORS AFFECTING THE ORGANIC-MATTER CONTENT OF SOIL

5.3.1. Climate

Climate is of major importance in determining the organic matter content of soil. Of the different components of climate, temperature and precipitation are the most important. Jenny (1930) observed that for each decrease of 10°C in annual temperature, the average organic-matter content of soil increased two to three times. The C:N ratio of the organic matter also increased as temperature decreased. Jenny further observed that at a constant temperature the organic-matter content of soils of the central United States increased logarithmically with the increase in available water supply. Similar conclusions were drawn by Jenny and Raychaudhuri (1960) for their studies on Indian soil. The ideal trend of organic soil N for large areas of loamy grassland soils of the United States is shown in [Figure 5.10](#). According to Jenny, the order of importance of different soil-forming factors in determining the organic-matter content of soil is as follows: climate > vegetation > topography > parent material > age. Theng et al. (1989), however, opined that the overall importance of the environmental factors determining soil C content is in the following order: rainfall > pH > clay content > temperature

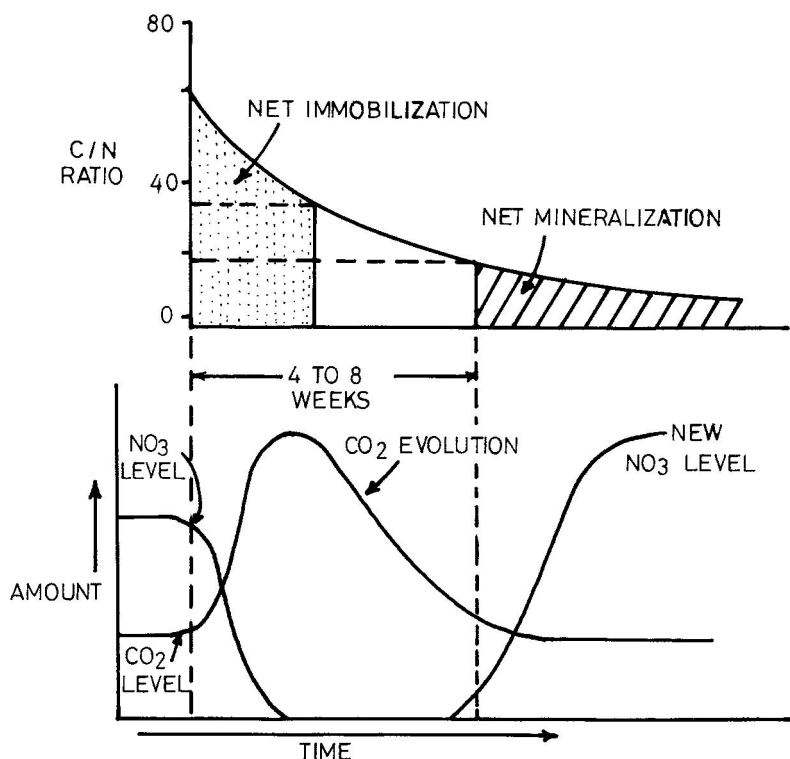


Figure 5.9. Changes in nitrate levels of soil during the decomposition of low-nitrogen crop residues. (From Stevenson, 1986. *Cycles of Soil — Carbon, Nitrogen, Phosphorus, Sulfur and Micronutrients*, pp. 13 and 166. With permission of John Wiley & Sons, New York.)

for tropical regions and rainfall > pH > temperature > clay content for temperate regions. The relationships between rainfall and soil organic C for tropical and temperate regions of Australia are shown in Figure 5.11 (Thang et al., 1989).

5.3.2. Texture

Under similar climatic conditions the organic-matter content in fine-textured soils is two to four times that of coarse-textured soil. While some of this could be attributed to increased oxidation in coarse-textured soils, two other important factors are (1) the formation of clay-humus complexes and (2) the formation of metal organic-matter complexes. Again, soils having 2:1 expanding-layer silicates have more organic matter than the soils having 1:1 nonexpanding-layer silicates.

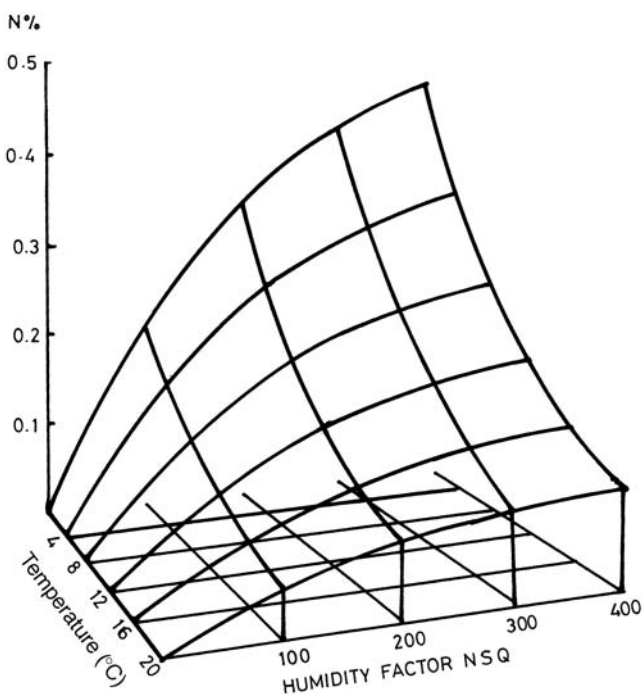


Figure 5.10. The nitrogen content of loamy grassland soils in the United States as a function of annual temperature and annual humidity factor (N.S.Q.). The curves express the approximate idealized trend of soil nitrogen of large areas. (From Jenny, 1930. Mo. Agric. Exp. Sta. Res. Bull. 324:66. With permission of University of Missouri, Columbia, MO.)

5.3.3. Agricultural Practices

Cultivation. When a forest land is brought under cultivation, the organic-matter content starts declining, and the decline depends upon climatic factors and the intensity of cultivation. In a classical study at Missouri (Jenny, 1933) about 25% of the soil organic N was lost in 20 years and 35% in 60 years. The data of Hobbs and Brown (1957) for a few locations in Kansas (Figure 5.12) show the loss of 50% N in some soils after 40 years of cultivation. In another study more than 50% of soil organic matter was lost in 50 years of cultivation (Bauer and Black, 1981). In long-term studies covering 60 to 80 years, carbon and nitrogen losses from Canadian prairie surface soils due to cultivation ranged from 50 to 60% and 40 to 60%, respectively (Campbell et al., 1976). Similarly, in an Australian study (Dalal and Meyer, 1986) carbon N nitrogen losses averaged 36% in soils cultivated for 20 to 70 years.

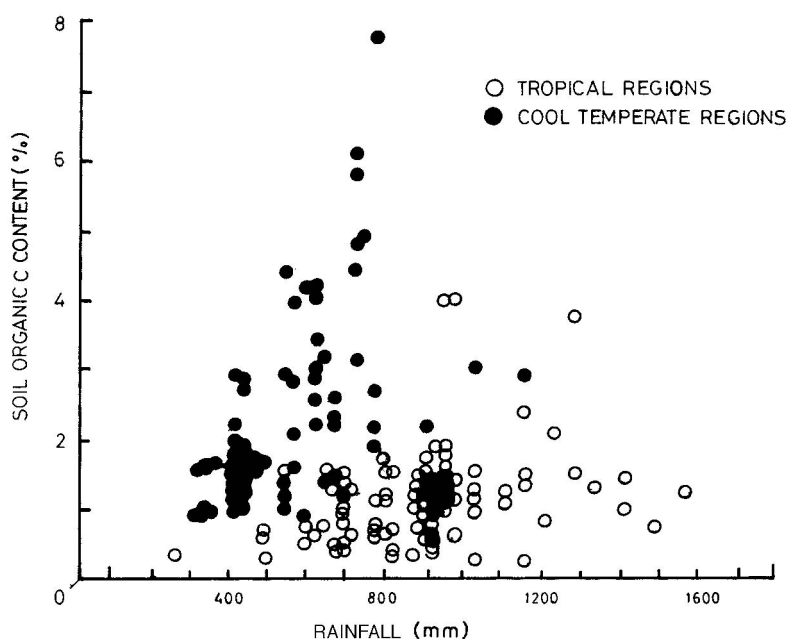


Figure 5.11. Relationship between organic carbon content and rainfall for ultisols (Krasnozems) from tropical, and cool, temperate regions of Australia. (From Theng et al., 1989. *Dynamics of Soil Organic Matter in Tropical Ecosystems*, p. 6. With permission of the University of Hawaii.)

Fallowing. Increasing the frequency of fallowing generally increases the loss of organic matter from the soil (Rasmussen and Collins, 1991). Haas et al. (1957) reported that cropland in grain-fallow rotation lost more organic N than did continuously cropped land at 13 or 14 locations throughout the midwestern United States; the average loss after 30 to 43 years of cultivation was 24% in the continuous small grain versus 29% with the grain-fallow cropping system. Similarly, Monreal and Janzen (1993) reported that after 80 years of cropping at Lethbridge in Alberta, Canada, the organic C loss was 23% under fallow-wheat, 21% under fallow-wheat-wheat, and only 17% under continuous wheat. In general, those cropping systems that return the most C to the soil usually exhibit the least loss of soil organic matter.

Tillage. Available information on tillage effects on soil organic matter and N availability leads to the following conclusions: (1) tillage of all kinds leads to a decrease in soil organic C and N as compared with native sod; (2) incorporation of crop residues as compared with their removal usually increases organic-matter content of soil; (3) leaving a crop residue cover on

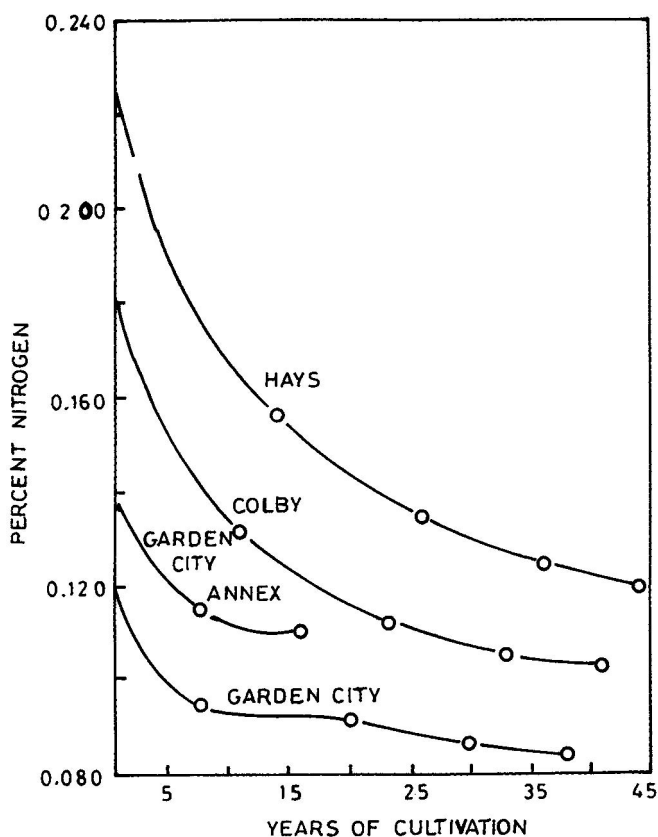


Figure 5.12. Effect of cultivation on nitrogen content of surface soils of Hays, Colby, and Garden City, Kansas. (From Hobbs and Brown, 1957. *Agron. J.* 49:259. With permission of the ASA, Madison, WI.)

the soil surface leads to an accumulation of organic matter and total N in the surface soil; and (4) burning of crop residues often produces a variable effect on soil organic-matter content, depending on soil depth, tillage practices, degree of burning, time, and other factors (Prasad and Power, 1991). Effects of conservation tillage on the soil organic-matter content are summarized in Table 5.4. Most of these data show a higher organic-matter content in soils under conservation tillage. Tillage generally increases oxygen content of soil air and exposes protected organic matter to microbial action; thus the more a soil is tilled, the greater the loss of organic matter.

In many Asian and African countries rice paddies are prepared by puddling, which is cultivation by a plough or harrow in a flooded field. Lal (1986) showed that puddling reduced the organic-matter content from 2.2 to 2.5% in

Table 5.4 Effect of Conservation Tillage on Organic C and N in Soil

Location and soil	Annual precipitation (mm)	Soil depth (cm)	Length of study (yr)	Tillage system ^a	Increase (%/yr)	
					C	N
South Africa						
Haploxeralf	412	10	10	TT	5.6	3.4
Haploxeralf	412	10	10	NT	7.3	5.1
Germany						
“Podsol”		30	5	NT	3.2	1.4
“Podsol”		30	5	NT	2.4	1.6
“Podsol”		30	6	NT	1.3	1.3
Australia						
Western						
Psamment	345	15	9	NT	1.6	—
Alfisol	307	15	9	NT	0.7	—
Alfisol	389	15	9	NT	1.4	—
Queensland						
Pellustert	698	10	6	NT	1.2	1.3
Canada						
Saskatchewan						
Chernozem		15	6	NT	6.7	2.8
United States						
North Dakota						
Haploboroll	375	45	25	SM	1.8	1.3
Haploboroll	375	45	25	SM	−0.1	0.1
Argiboroll	375	45	25	SM	0.5	0.4
Kansas						
Haplustoll		15	11	NT	0.7	0.6
Nebraska						
Haplustoll	446	9	15	NT	2.8	2.4
	446	10	15	NT	1.2	1.0
Oregon						
Haploxeroll	416	15	44	SM	0.3	0.4
Washington						
Haploxeroll	560	5	10	NT	1.9	2.0

Table 5.4 Effect of Conservation Tillage on Organic C and N in Soil (Continued)

Location and soil	Annual precipitation (mm)	Soil depth (cm)	Length of study (yr)	Tillage system ^a	Increase (%/yr)	
					C	N
Mean					2.2	1.7
Minimum					-0.1	0.1
Maximum					7.3	5.1

^aTT, tine-till; NT, no-till; SM, stubble-mulch

Adapted from Rasmussen and Collins (1991).

no-till plots to 1.5 to 1.9% under puddling in a 0- to 5-cm layer of surface soil over 6 years.

5.3.4. Fertilizers and Manures

Continued application of organic manures is well known to increase soil organic matter (Rasmussen and Collins, 1991). The application of chemical fertilizer leads to better development of roots, and even if grain and straw is removed, additional root mass can increase soil organic-matter content. Data from long-term manurial experiments in India (Nambiar et al., 1992) are given in Table 5.5. At only three out of eight centers was there a decrease in soil organic-matter with fertilizer application; at the other five centers there was an increase in soil organic matter due to fertilizer application. Thus the myth that fertilization leads to impoverishing of soil fertility is not true, at least for soil organic matter. Nevertheless, the increase in soil organic matter was most when FYM (farmyard manure) was applied along with chemical fertilizer.

Table 5.5 Changes in Soil Organic C (%) as Affected by Fertilizer and Manure (Over the Years 1971–1989)

Location	Soil class	Cropping system	Initial (1971)	NPK (1989)	NPK + FYM (1989)
Barrackpore	Eutrochrept sl	R-W-J ^a	0.71	0.46	0.53
Ludhiana	Ustochrepts ls	M-W-C	0.21	0.28	0.40
Jabalpur	Chromustert c	S-W-M	0.57	0.59	1.11
Hyderabad	Tropaquept scl	R-R	0.51	0.70	1.28
Ranchi	Haplustalf sic	S-P/T-W	0.45	0.33	0.38
Bhubaneswar	Tropaquept s	R-R	0.27	0.56	0.80
Palampur	Hapludalf sil	M-W	0.79	0.96	1.57
Pantnagar	Hapludoll sicl	R-W-C	1.48	0.86	1.45

^aR, rice; W, wheat; J, jute; C, cowpea (fodder); M, maize; S, soybean; P, potato; T, toria. From Nambiar et al., 1992. Annual Report 1988–89 of (ICAR) Indian Agricultural Research Institute, New Delhi.

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